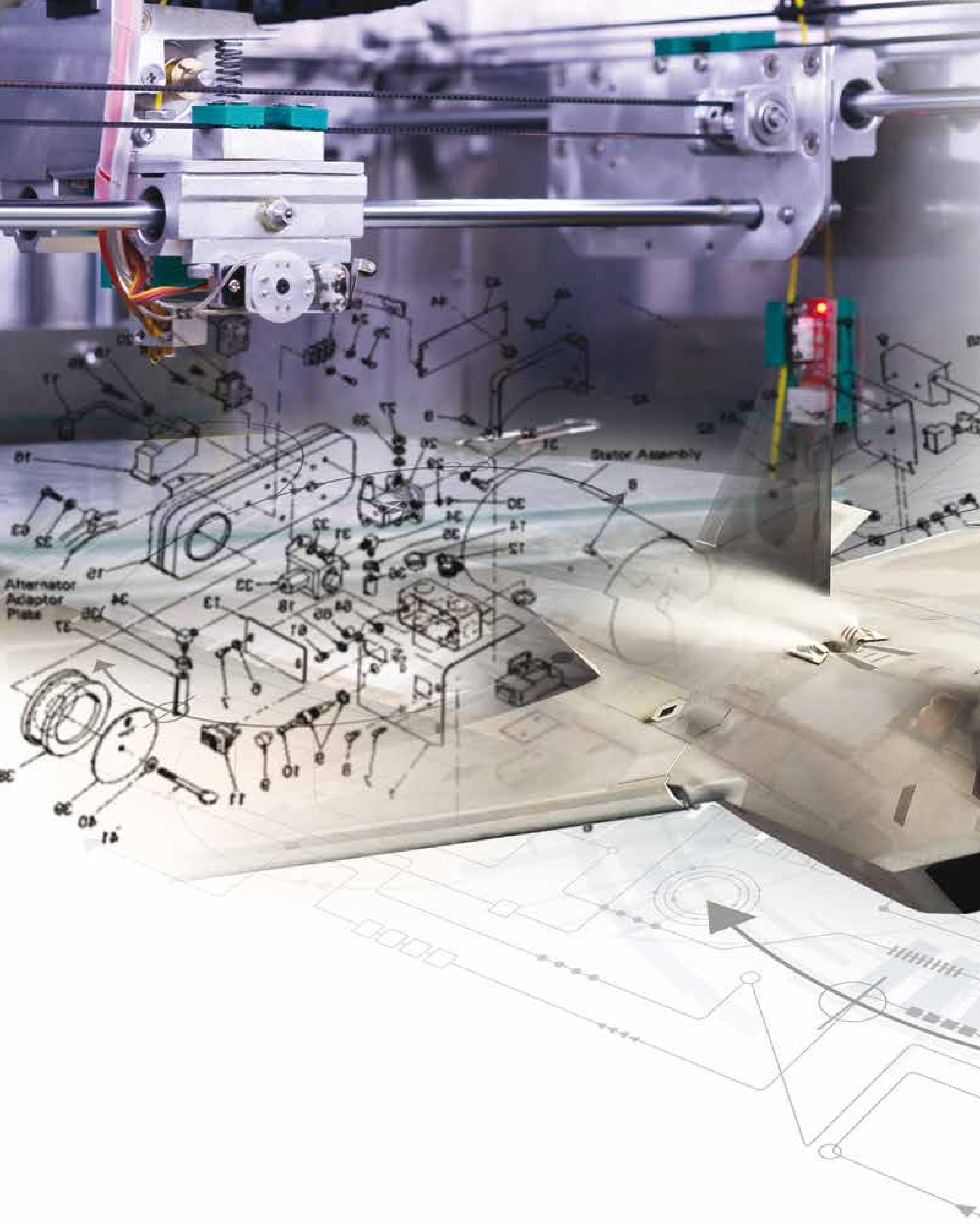
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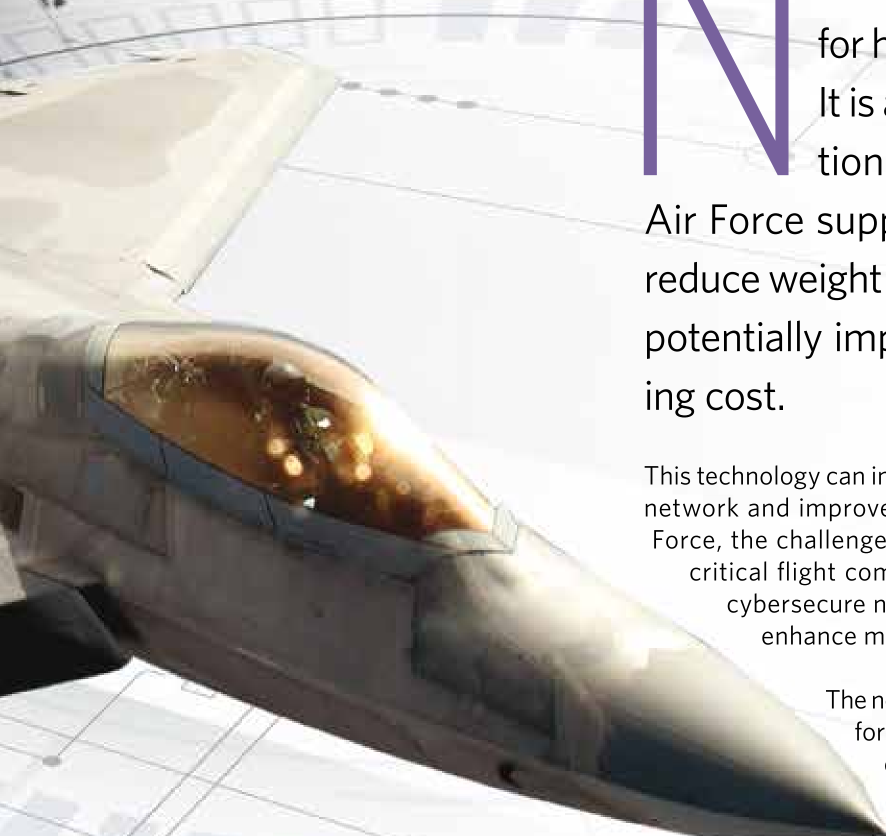
Challenges of Enterprise-Wide AM for Air Force Sustainment

Debora Naguy



No one challenges the massive potential of Additive Manufacturing (AM) for high-tech aerospace components. It is a cost-effective, tool-less production that can address many current Air Force supply chain challenges. It also can reduce weight through lightweight design while potentially improving performance and reducing cost.

This technology can improve asset velocity to the Air Force supply chain network and improve mission readiness and availability. For the Air Force, the challenge is how to safely implement the technology for critical flight components and smartly implement an integrated cybersecure network of rapid, agile repair capabilities that will enhance mission generation.

The near-term potential of this game-changing technology for tooling, fixtures, support equipment and noncritical aerospace components can help the Air Force to establish a strong foundation for expanding AM to critical aerospace components. A strong enterprise foundation across the Air Force "ecosystem" is the critical first step to smartly leverage the technology and rapidly gain knowledge needed for further expansion. A deliberate, planned approach that focuses on establishing enterprise processes, enterprise tools and standardized equipment and skillsets across all major commands will allow the Air Force to realize infrastructure and support operational agility as called for in the Air Force Future Operational Concept

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(AFFOC). By leveraging and expanding this technology smartly and quickly, the Air Force can acquire the advantage that this technology can provide today and into the future.

To truly capitalize on the full potential of AM, the Air Force Life Cycle Management Center (AFLCMC) in close collaboration with the Air Force Research Laboratory (AFRL), the Air Force Sustainment Center and the Air Force Nuclear Weapons Center (AFNWC) are aggressively addressing the challenges of AM while using a collaborative, enterprise approach to implementation.

The true potential of this technology will be realized through a centralized and global network approach leveraging both the Engineering and Logistic/Maintenance communities across the Department of Defense (DoD). The Air Force Materiel Command team developed an AM Implementation Plan (AMIP) that takes a deliberate approach to the various challenges associated with AM across the Air Force Enterprise employing collaboration and agile methodologies. The AMIP establishes a strong foundation using standardized equipment, processes, tools and procedures across the entire Air Force. Implementing an effective AM network across a large network of air bases throughout the world, maintenance and repair organizations, engineering disciplines, and numerous weapon system program offices requires new processes, leverages the Repair Network integration effort and allows the Air Force to utilize an agile deployment methodology.

Other challenges being addressed include developing material standards, skill-set development for engineers and operators, part selection methodologies, configuration control, reproducibility, standardized library of qualified parts with technical data packages (TDPs), cybersecurity, validation and qualification procedures, and reverse engineering. This article dives into each of these challenge areas in more detail.

Selecting the right AM material and process is a key foundational requirement in successful AM implementation and will directly affect the expected return on investment. Whether the AM product is for a prototype, first article testing, repair or an end-use production part, understanding the application is the first step. There are hundreds of materials and numerous process choices to consider. The right choice for the application is critical to ensure desired mechanical properties can be achieved. Geometry, function and post processing are all considerations as well as end-item cost considerations.

AM designers will need to be creative, innovative, and utilize a new design methodology that will take advantage of the technology. Close collaboration and innovation with academia and industry are key components.

The approach for material standards and quality include understanding powder characteristics, developing an enterprise material characterization database, and developing standards for powder requirements based on the component requirements. For example, an AM tool does not require the same level of material quality as a critical aerospace component. The other military Services, industry and academia also are working to address many of these challenges including material standards. The AMIP looks to leverage all work being done to ensure we capture all the knowledge that has already been generated in this area to speed implementation. Standardized tools to help in selecting the materials are being investigated for adoption across the enterprise.

The aerospace community must invest in the skills of people who will design, build and use AM technology across the aerospace industry. The majority of today's engineers have been trained to utilize conventional engineering methods using subtractive design principles. Switching that paradigm will take time and deliberate steps. AM designers will need to be creative, innovative and utilize a new design methodology that will take advantage of the technology. Close collaboration and innovation with academia and industry are key components of the AMIP that will help shape the future aerospace workforce.

However, we also will need to rapidly retrain and rethink the way our traditional engineers were taught for conventional design. The target audience of the skillset development plan includes both new and experienced engineers, designers, operators, supply chain and maintenance communities. The AMIP includes leveraging partners across academia and industry to ensure new engineers and/or technicians entering the Air Force have the necessary AM foundational skills.

Internal Air Force training programs are being developed that will baseline and develop the workforce.

Training outputs include standardized understandings with strong AM foundations, including both technical and economic considerations. For both engineers and operators, advanced AM training is being developed and will focus on the design principles necessary to efficiently and effectively utilize AM. Focus areas for internal training will include fundamentals of AM designs, design strategies for AM, quality control, safety operations, AM materials selection, and hands-on design and print projects for Air Force AM components. This approach will allow the Air Force to effectively standardize tools, design principles, configuration control, quality control and validation procedures, while building a centralized library of qualified, validated designs.

The maturing of AM technologies has made possible broader AM application. The screening and selection of parts are other important and foundational processes necessary for each potential application. AFLCMC is developing a standardized, systematic approach to selecting parts, materials and processes for AM across the Air Force enterprise. The opportunity for cost-effective readiness is important, and using a value chain approach that takes into consideration both economic and readiness criteria will ensure the correct applications are pursued.

As an enterprise, the Air Force is identifying the critical criteria that must be considered during the selection process. We are using a crawl, walk, run approach to down-select and test the criteria on a small selection of initial parts.

As a whole, the DoD has different drivers and mission needs that will influence the part selection decision even when it is a non-economical choice to support the mission. Traditional manufacturing companies typically use cost or performance as a primary driver in making decisions. The Air Force is interested in new deployment concepts that leverage agile manufacturing to support our warfighters through reduced logistics footprints and agile deployment.

Our maintenance and repair organizations will be able to leverage the technology to help address the issues of diminishing manufacturing sources of supply and to increase asset velocity. Many of our legacy aircraft no longer have parts manufacturers, and therefore reverse engineering and rapid manufacturing are critical requirements. AM also may reduce our vulnerability to supply disruption if adequate cybersecurity is provided. These considerations are being included in the planning and down-selection process.

AFLCMC also is developing standard implementation plans, standard procedures, and standard configuration control processes for all aspects of the AMIP to ensure configuration control is maintained. Strong configuration control principles can ensure the current design and build state is known, good and trusted, meets the design intent and is repeatable. As the Air Force brings onboard new AM machines and post processing equipment, standard facility guides and safety standards and hazard risk assessments are being developed for each type of equipment. Configuration control across all aspects of design, print and qualification will be critical to ensuring correct and repeatable performance. Lack of configuration control could lead to a failure of a critical flight component and contribute to a catastrophic mishap. These standards will enhance system reliability and reproducibility through more rapid detection and correction of improper configuration that could negatively impact component design and build properties.

The ability to utilize standard asset identification, in-process monitoring, quality control procedures, and verification and validation principles is critical to safely implementing AM technology in critical aerospace applications. Cost-effective readiness will be achieved through detailed knowledge, documented across all configuration elements to ensure unnecessary duplication is avoided. This will allow the Air Force to achieve greater agility and faster implementation while decreasing risk, improving security, and ensuring that safe

U.S. Air Force Approach to Additive Manufacturing

Material standards and availability. Creating AF specs and developing material properties database using enterprise approach, evaluating powder vendors

Part selection. Develping enterprise-wide down-selection tools and process guides

Skillset development. Evaluating standard AM design tools, developing AM training for engineers and operators in AM concepts/designs for enterprise deployment

Configuration control. Establishing centralized library, standard TDPs, standard process and policies for facility layout, quality control, and material evaluation

Reproducibility. Evaluating process controls and demonstrating manufacturing variations at major commands and depots

Cybersecurity. Developing program protection plans and evaluating secure digital design storage and data transfer to move files for cyber resiliency

Part validation and qualitication. Establishing standard process for NDI and validation

Process validation and qualification. Establishing a robust and sustainable enterprise process

Reverse engineering. Evaluating tools and training for legacy part TDPs

practices are employed and do not produce new incompatibilities or potential failures.

A cybersecure library of digital AM designs with digital TDPs ready to print on any certified machine across the Air Force enterprise is another key component of the AMIP. An ability to share approved TDPs across the Air Force enterprise will reduce duplication, improve readiness, and better support the Air Force mission. It is essential that the digital TDP prints as designed ensure critical part performance across any of the network AM printers; this critical challenge is being addressed through the AMIP. For example, machine-to-machine variations will be minimized through tight configuration control and quality practices.

A critical step in the AM process is validating the integrity of building a part. Confident validation and qualification will be achieved by analyzing parts through Non-Destructive Inspections (NDI) and destructive testing in a systematic manner comparable with existing data. However, these techniques are costly and time consuming and require their own training and skillset demands.

As we build a multitude of parts and gain the knowledge and confidence of the AM process while monitoring the process, we will be able reduce our demand on these NDI technologies. And we will be able to establish lower-cost quality control technologies for quick verification and validation of parts produced by AM operators. This will enable us to respond faster

While the digital thread concept enables a more efficient design process, it also presents opportunities for cyber risk to disrupt our supply chain.

to supply chain demands. AFLCMC in close coordination with the AFRL will continue leveraging and participating in industry efforts to further expand this capability.

Cybersecurity is another challenge being addressed today in conjunction with digital data requirements in the AMIP. Vulnerability assessments across the entire AM process (both information technology and physical systems) are being performed and will be assessed continually. Program protection plans are being developed to ensure the technology, the TDPs and the standardized library do not become disrupted by our adversaries. We must understand the cybersecurity risks and challenges before implementing effective solutions. AFLCMC is addressing and building cyber safe practices into the AM capability early through the use of actionable intelligence.

While the digital thread concept enables a more efficient design process, it also presents opportunities for cyber risk to disrupt our supply chain. AFLCMC is leveraging a vast array of cybersecurity tactics and technologies to ensure safe AM deployment through real chain custody of authentication. A few examples include designing anti-tamper markings and serial identification built into part designs that must be validated prior to print. Equipment access will be restricted with state-of-the-art technology to ensure only certified operators on certified machines have access to the process. Ubiquitous data collection and pervasive analytics will be employed to detect disruption. Cyber Failure Mode, Effects, and Criticality Analysis will be accomplished to ensure every potential vulnerability is understood.

Using an enterprise approach to implementing AM will raise weapon system maintenance and sustainment to the power of "Collaborative Logistics." Successful integration of AM technology relies on a strong foundation of standardized processes that meet and address the AM challenges. These methods outlined in the AMIP will provide this enterprise approach and allow for a repository of fully validated, qualified AM designs, ensuring every 3D printed part meets or exceeds original design intent in a secure, digital environment. Using a converged integrated network will make possible the close collaboration and partnering that will advance the technology throughout the Air Force ecosystem quickly and safely. Starting with and proving the technology on noncritical parts will help manage risk while progressing the technology more quickly. And, by overcoming these challenges, we will create a solid foundation for a future supply chain with a vastly increased potential to support readiness. The benefits of AM are numerous and will allow the Air Force to adapt swiftly to the threat by using an agile infrastructure supporting operational agility through a smaller footprint, increased flexibility and on-demand supply support.

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